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IMPACTITES AND TEKTITE-LIKE BODIES FROM LONAR CRATER, INDIA

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2 Figures

3 Tables

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The origin of tektites as splashed glass bodies produced during meteorite or asteroid impact on the terrestrial rocks has been widely accepted, however the correlation of tektites to a specific impact site has been difficult. We have analysed two distinct populations of glasses from the immediate vicinity of the Lonar crater, India. One population which we call impactites, essentially consists of texturally heterogeneous impact melts of local basalts (~51 wt% SiO_2) without significant material addition. The other population consists of homogeneous, dense high silica splash form glass bodies (~67 wt% SiO_2) found within a one kilometer radius of the crater rim. These high silica tektite-like glass bodies seem to be impact melt products of 2/3 local basalt and 1/3 siliceous material. In the association of the impactites and tektite-like bodies, Lonar crater seems to be analogous to Zhamanshin crater in the USSR.

Lonar lake (19^{o} $58'$N,$76^{o}31'$E) is a young meteorite impact crater[1,2] in Deccan basalts,Buldana Dt., Maharashtra State, India. The impact melts from Lonar crater are generally vesicular and heterogeneous, characterised by the presence of schlieren, relict pyroxene, plagioclase and skeletal opaque mineral grains[1,3]. Petrographic and major element data of these glasses clearly indicate that these are impact melt products of local basalts. There is a continuous transition from moderately shocked basalts to these impact melts[1,3,4] which we refer to as impactites[5,6] in this study.

In addition to these impactites, dense black glass bodies of varying sizes (1mm to 5cm), with distinct aerodynamic shapes, are also reported[7] from the eastern and western ejecta deposits of the Lonar crater. Though the exact areal distribution of these small, isolated glass bodies is not known, their spatial density varies from 10 to 900 per sq.m[7] and they are noticed up to a distance of ~ 1km from the crater rim. Megascopically these glass bodies vary from dull to lustrous black varieties with pitted surfaces and distinct flow features (Fig 1A) and one of the glasses in our collection resembles a congealed drop of viscous liquid (Fig 1B). Broken pieces of these glasses appear transparent or translucent(Fig 1C) exhibiting shades of pitch black or greenish black colours. Thin section study revealed that these are texturally homogeneous glasses showing occasional schlieren and strained birefringence, and both circular and elliptical vesicles are noticed in some of these glasses(Fig 1D).

We conducted a systematic study of these glasses employing electron microprobe (major elements) and instrumental neutron activation analysis (Fe, Na, Co, Cr,Sc, Th, Hf, Ta, Ba, Cs and REE). Volatiles (CO_2, H_2O) were measured by microcrushing and computer controlled quadrapole mass spectrometry[8]. Five basalt flows and two impactite samples from the Lonar crater and the Georgia tektite[9] were also included in the study for comparison. Data are presented in tables 1,2 and 3.

Two distinct groups are identifiable in the data. Lonar impactites and basalts(~51 wt% SiO_2) form the first group with identical major and trace element abundances (Tables 2 and 3). The data of eleven morphologically different splash form glass bodies represents the chemically coherent second group with significantly higher silica (65-68 wt%) and correspondingly lower concentrations of the rest of the major and trace elements(Tables 1 and 3). However, considerable variation is noticed in the Na_2O (1.42- 6.92 wt%), FeO (total Fe as FeO; 5.83- 9.28 wt%) and CaO (5.80-6.90 wt%) contents of these high silica glasses (Table 2).

These Lonar high silica glasses satisfy the criteria adopted for identification of tektites[11]. They contain 65%-68% silica, aerodynamic and flow features and are dispersed over a strewn field extending at least 1km from the crater rim. They are depleted in H_2O (0.095 wt%) and enriched in CO_2/H_2O mole ratios (~0.15)compared to Deccan basalts (H_2O: 1-2 wt%; CO_2/H_2O:~0.009) similar to Georgia (H_2O: ~0.09 wt%; CO_2/H_2O:0.21) and other tektites[12]. Small spherules resembling " microtektites " usually associated with tektite strewn fields[11] are also reported from this area[13].

Comparable major and trace element compositions of the Lonar impactites and basalts clearly indicate that the impactites are the direct impact melt products of local basalts without any significant material addition. On the other hand, the tektite-like bodies seem to be related to the local basalts by silica addition resulting in the over all dilution of the rest of the major and trace elements (Fig 2A and 2B and Table 3). If about 33% of a siliceous material is added to the local basalts the resulting major element composition is remarkably similar to the composition of these tektite-like bodies(Table 2). Identical but depleted REE patterns of these tektite-like bodies compared to local basalts and impactites clearly suggest the genetic affinity of these glasses to local basalts by silica dilution(Fig 2B). Interestingly, a similar systematic depletion in the REE patterns in the tektite-like bodies(Irghizites) relative to the local impactites (Zhamanshinites)is observed[14] among the samples from the Zhamanshin crater in the USSR where in the impactite and tektite-like bodies association is well established[15]. Recent study indicated[16] that the Ivory coast tektites also, are formed by mixing of free silica with the Bosumtwi crater target rocks.

We have not identified the high silica component at the Lonar site and suggest the evaluation of two plausible sources in this connection. One is the abundant secondary silica usually present in the weathered zones of Deccan flows which is attributed to the weathering of basalts and /or to the late magmatic fluids[17]. Inter-trappean sediment[18] is the second possible source of excess silica. In fact, based on crater morphology studies, Fudali et al[2] concluded that the preimpact target at the Lonar crater consisted of two or more incompetent layers (inter-trappean sediments ?) sandwiched between the tough competent (basalt) layers, and Venkatesh[19] reported a highly weathered formation resembling sandstone from the crater wall. Thus it is necessary to examine the precrater soil[2] and the local inter-trappean sediments to identify the source of high silica component at Lonar.

The association of both impactites and tektite-like bodies even at the small (~2km diameter) Lonar crater clearly demonstrates the possibility of formation of tektites due to meteorite impact. This supports the hypothesis that tektites represent the splash form glass bodies produced from the terrestrial rocks due to the large scale hypervelocity impact events of extraterrestrial bodies on the earth[20,21]. The Lonar crater in India appears to be a basaltic analogue of the Zhamanshin crater in USSR, in the simultaneous occurence of both impactites and tektite-like bodies.

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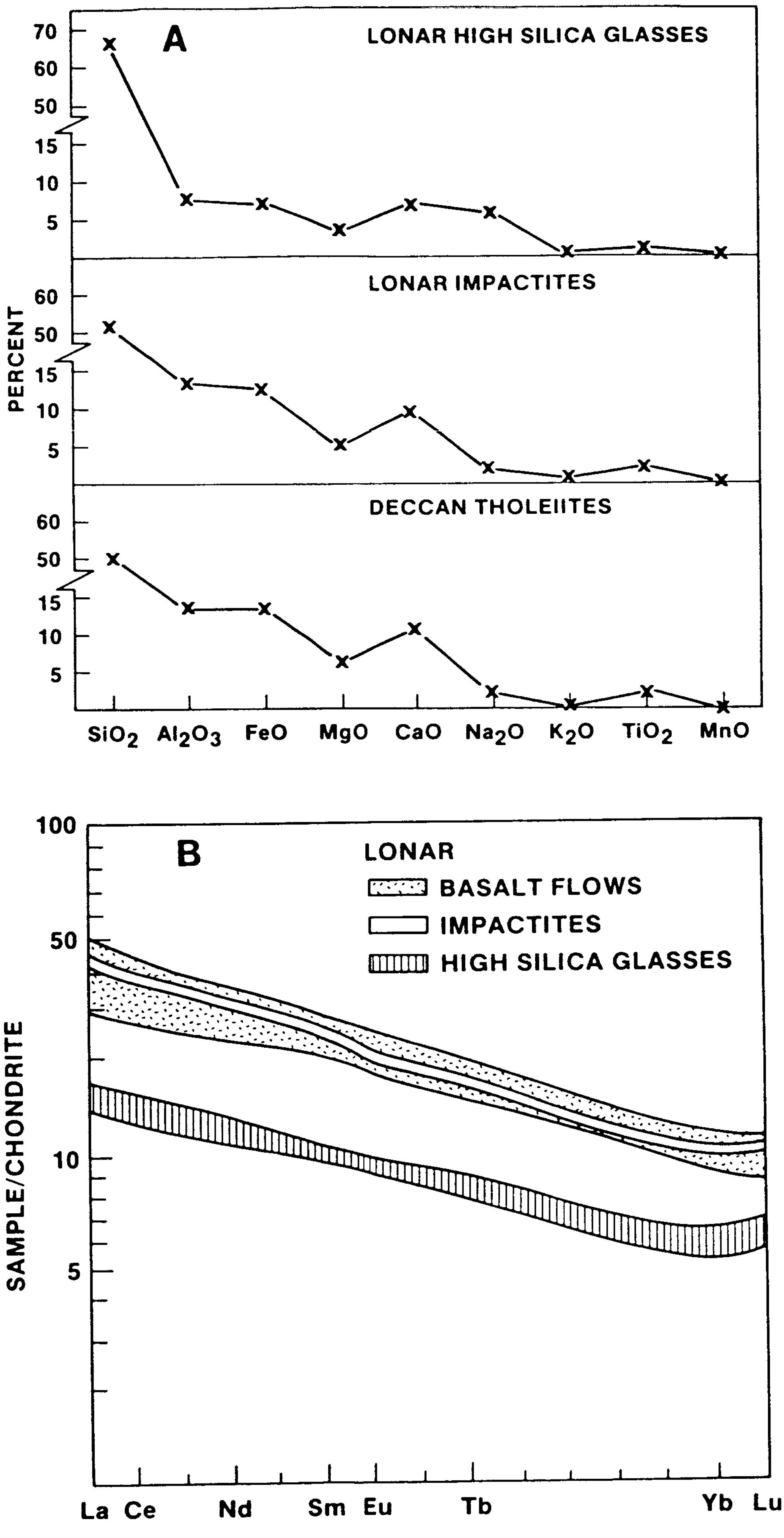
FIGURE CAPTIONS

Fig 1 A. Dense glass fragments with pitted surfaces and flow features. B. Dark glass fragment resembling congealed drop of viscous liquid. C. Broken pieces of the glasses under microscope. D. Elliptical vesicles (microphotograph) in some of the glasses.

Fig 2 Chemical variations among basalts, Lonar impactites and the high silica glasses (tektite-like bodies). A. Major oxides (Wt%). B. Chondrite normalized REE patterns (Data in tables 2 and 3).


A
LONAR HIGH SILICA GLASSES
LONAR IMPACTITES
DECCAN THOLEIITES
PERCENT
70
60
50
15
10
5
SiO_2 Al_2O_3 FeO MgO CaO Na_2O K_2O TiO_2 MnO
B
LONAR
BASALT FLOWS
IMPACTITES
HIGH SILICA GLASSES
SAMPLE/CHONDRITE
100
50
10
5
La Ce Nd Sm Eu Tb Yb Lu

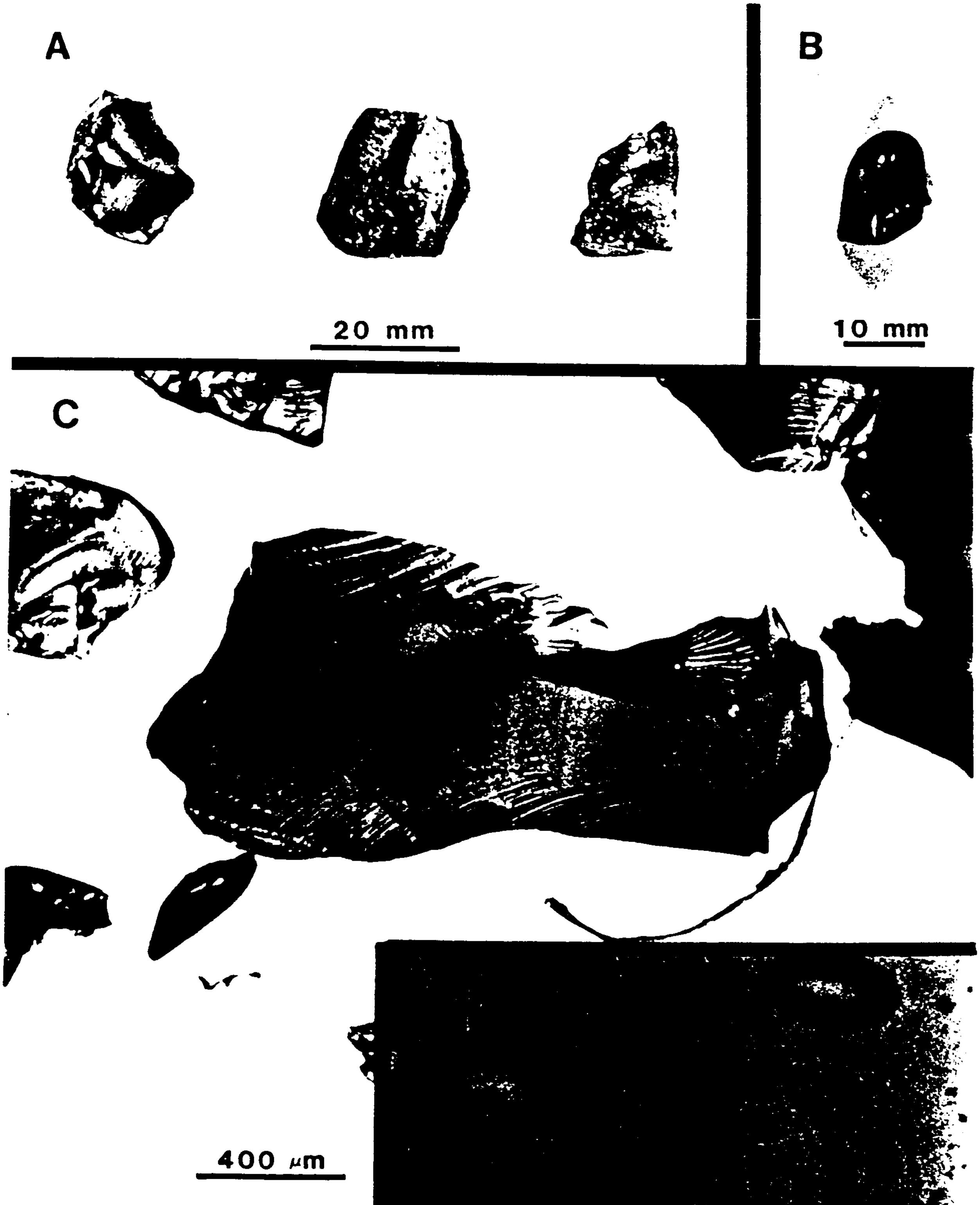

A
20 mm
B
10 mm
C
400 µm

Table 1. MAJOR ELEMENT ABUNDANCES (WT %) OF THE TEKTITE-LIKE BODIES, LONAR CRATER, INDIA

OXIDE %	#1	#2	#3	#4	#5	#6	#7	#8	#9	#10	#11
SiO_2	67.59	67.57	67.46	66.95	66.12	66.02	67.87	67.50	64.50	67.29	66.40
Al_2O_3	7.88	8.03	8.20	8.95	7.91	8.75	8.73	8.90	8.51	8.22	7.98
TiO_2	0.92	0.88	1.10	1.39	1.39	1.49	1.77	1.91	1.16	0.92	1.57
MgO	3.65	3.70	3.74	3.40	3.79	3.65	3.19	3.40	4.13	3.75	3.61
FeO	5.88	5.86	5.83	7.15	6.99	8.37	8.21	9.28	6.97	5.91	8.55
CaO	5.80	5.96	5.80	5.96	6.36	6.17	6.90	5.89	6.87	5.87	6.35
Na_2O	6.92	6.85	6.91	5.12	6.62	4.08	1.91	1.42	6.59	6.90	4.04
K_2O	0.33	0.31	0.30	0.26	0.35	0.32	0.27	0.46	0.34	0.30	0.25
MnO	0.12	0.12	0.13	0.16	0.10	0.16	0.12	0.20	0.10	0.09	0.15
TOTAL	99.09	99.28	99.47	99.34	99.63	99.01	98.97	98.96	99.17	99.25	98.90

Table 2. MAJOR ELEMENT ABUNDANCES OF DECCAN BASALTS, IMPACTITES AND THE TEKTITE-LIKE BODIES FROM LONAR CRATER, INDIA

OXIDES %	DECCAN THOLEIITES# m s	IMPACTITES* m s	IMPACTITES (THIS WORK) m s	HIGH SILICA GLASSES (THIS WORK) m s (RANGE)	MIXING MODEL (2/3 BASALT+ 1/3 SILICA)
SiO_2	50.02+0.80	51.77+3.27	51.05+1.55	66.84+1.00 (64.50- 67.87)	66.68
Al_2O_3	13.43+0.81	13.46+0.79	13.57+0.30	8.37+0.41 (7.88- 8.95)	8.95
TiO_2	2.38+0.58	1.99+0.60	2.14+0.03	1.32+0.35 (0.88- 1.91)	1.59
MgO	6.40+1.01	5.30+0.50	5.05+0.48	3.64+0.25 (3.19- 4.13)	4.26
FeO	13.49+1.33	12.54+1.28	13.82+1.74	7.18+1.25 (5.83- 9.28)	8.99
CaO	10.72+0.70	9.88+1.33	9.74+0.85	6.18+0.40 (5.80- 6.90)	7.14
Na_2O	2.27+0.23	2.25+0.28	2.36+0.23	5.21+2.07 (1.42- 6.92)	1.51
K_2O	0.36+0.11	0.59+0.35	0.64+0.08	0.32+0.06 (0.26- 0.46)	0.24
MnO	0.23+0.03	n.d	0.16+0.04	0.13+0.03 (0.09- 0.16)	0.15

FeO: total Fe as FeO; n.d: not determined; m: mean; s: standard deviation

Based on data of 100 flows covering Mahabaleshwar, Igatpuri and Jabalpur areas (Mahoney, 1984)[10]

* Brown glass (24 samples) data(Schaal, 1976)[3]

Table 3. INAA DATA OF BASALTS, IMPACTITES AND TEKTITE-LIKE BODIES FROM LONAR CRATER, INDIA

	BASALTS					IMPACTITES		TEKTITE-LIKE BODIES			
ELEMENT	AU83-15	AU83-16	AU83-17	AU83-18	LON-BSLT	KFDB-1	KFDB-2	#1	#3	#4	#7
FeO%	12.86	11.19	11.93	11.10	12.50	12.50	12.10	6.10	6.11	7.40	8.12
Na_2O%	2.07	2.48	2.16	2.42	2.35	2.30	2.25	7.12	7.01	6.88	2.14
Co ppm	43	44	41	39	42	44	45	25	25	21	26
Cr	35	113	66	101	56	90	95	44	41	39	41
Sc	31	30	32	32	32	32	34	17	17	18	16
Hf	3.5	3.0	4.0	3.5	4.6	3.9	3.7	1.8	1.9	1.5	1.9
Ta	0.5	0.5	0.7	0.5	0.8	0.6	0.5	0.3	0.3	0.3	0.4
Th	1.6	1.2	2.2	1.6	2.5	2.7	2.8	1.1	1.1	1.1	1.4
Ba	130	110	137	155	200	200	160	110	60	95	90
La	11.3	10.9	13.7	11.6	18.3	16.1	16.6	5.7	5.6	5.4	6.3
Ce	28	26	34	30	41	36	38	14	13	12	15
Nd	18	17	24	20	25	22	24	9	8	8	9
Sm	5.3	5.0	5.7	5.3	6.5	5.7	6.0	2.4	2.4	2.2	2.5
Eu	1.75	1.65	1.83	1.68	2.13	1.75	1.82	0.78	0.83	0.82	0.87
Tb	1.05	0.87	0.98	0.90	1.16	1.10	1.05	0.48	0.44	0.42	0.53
Yb	2.51	2.30	2.53	2.23	2.87	2.80	2.75	1.40	1.42	1.14	1.42
Lu	0.39	0.35	0.40	0.32	0.44	0.42	0.40	0.22	0.23	0.19	0.24

FeO: total Fe as FeO; Estimated errors (1 sigma) based on counting statistics are $\pm$0.3-1% for Fe,Co and Sm; $\pm$1-3% for Cr, Na, Sc, La and Eu; 3-5% for Ce, Yb and LU; $\pm$7-12% for Th, Hf and Tb; $\pm$12-18% for Ta and Ba, and $\pm$20-29% for Nd.

AU83-15 to AU83-18 different basalt flows sampled from crater rim starting from the top. LON-BSLT: stray basalt sample collected from ~ 0.5km away north from the crater rim.